$\pi^- p$ Backward Elastic Scattering from 2.38 to 3.00 GeV/c†

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This paper presents differential cross sections for backward $\pi^- p$ elastic scattering in the angular region $-0.55 \geq \cos\theta_{c.m.} \geq -0.98$ for five incident momenta: 2.38, 2.50, 2.65, 2.80, and 3.00 GeV/c. The structure of the angular distribution undergoes a marked change over this momentum interval. A pronounced dip near 180°, which is seen for momenta $\lesssim 2.50$ GeV/c, becomes a sharp peak at 2.80 and 3.00 GeV/c. A minimum in the cross section at $\cos\theta_{c.m.} \simeq -0.7$ is indicated at all momenta. In addition, a dip in the differential cross section appears at $\cos\theta_{c.m.} \simeq -0.92$ at 3.00 GeV/c. A good fit to the data from 2.1 to 3.0 GeV/c is obtained with a direct-channel resonance model.

THE results presented in this paper are from an optical spark-chamber experiment performed at the Argonne National Laboratory zero gradient synchrotron. The purpose of the experiment was to measure angular distributions for backward $\pi^\pm p$ elastic scattering. Results for $\pi^+ p \to p\pi^+$ have been published.[1] The $\pi^- p$ differential cross sections given here represent 3100 elastic events (from 59 000 pictures) and cover the range $-0.8 \lesssim u \lesssim 0.1$ (GeV/c)^2. The range in pion c.m. angle is $-0.55 \gtrsim \cos\theta_{c.m.} \gtrsim -0.98$.

The experimental arrangement and the treatment of the data are described in Ref. 1. The beam intensity averaged 5×10^4 negative particles per burst, of which $(91 \pm 6)\%$ were pions. The ratio of elastic events to pictures was 8.1% at 2.38 GeV/c and 2.7% at 3.00 GeV/c. A background subtraction was made at each datum point and was typically 0–5% with a maximum of 20% near 180° at 3.00 GeV/c. We have plotted $d\sigma/d\Omega$ versus $\cos\theta_{c.m.}$ in Fig. 1 for data from 2.08 to 3.00 GeV/c. Data from other experiments[2–7] are also shown in Fig. 1. At 2.50 GeV/c, the four experiments shown in Fig. 1 are in good statistical agreement. There is, however, some difference between data from this experiment at 2.80 GeV/c and the data near $\cos\theta_{c.m.} \simeq -0.9$ at 2.85 GeV/c from the CERN-Saclay collaboration.[3] The data from this experiment are summarized in Table I. The errors given are statistical and were computed by the formula

$$\Delta d\sigma/d\Omega / d\sigma/d\Omega = [(S+2B)/S]^{1/2},$$

where S is the net signal and B the number of background counts. The uncertainty in over-all normalization is $\pm 7\%$.

At 3.00 GeV/c there appear to be dips in $d\sigma/d\Omega$, which are not apparent at higher momenta,[3] at $\cos\theta_{c.m.} \approx -0.92$ and $\cos\theta_{c.m.} \approx -0.7$. This latter dip can be seen in the data at some lower momenta as indicated by the arrows in Fig. 1. The dip seems to be appearing for a constant $\cos\theta_{c.m.}$ (≈ -0.7). At 3.00 GeV/c, the data suggest a peak in $d\sigma/d\Omega$ somewhere in the interval $-0.6 \leq \cos\theta_{c.m.} \leq -0.4$. Recent results from Brabson *et al.*,[8] which extend over $-0.6 \leq \cos\theta_{c.m.} \leq +0.9$ and which are in good statistical agreement with the data of Ref. 6 and this experiment, confirm the existence of a peak in the $\pi^- p$ cross section at $\cos\theta_{c.m.} \simeq -0.4$.

Another interesting feature of the data is the behavior of the differential cross section near 180°. At the lower momenta, through 2.50 GeV/c, the cross section is turning over sharply near 180°. At 2.65 GeV/c, $d\sigma/d\Omega$ is nearly level and at the higher momenta it is turning up sharply. The rapidly changing shape of the angular distributions in this momentum region is quite remarkable, particularly in light of the fact that from 2.38 GeV/c to 3.00 GeV/c there is only a 240-MeV increase in the c.m. energy.

The curves shown in Fig. 1 are a fit to the data using only direct-channel resonances, following a model proposed by Crittenden *et al.*[9] The model assumes all resonances in the πp system lie on Regge trajectories of uniform slope; one then postulates the existence of a large number of Regge recurrences of experimentally known resonances. The lowest-mass states of the trajectories used in the fits are listed in Table II. The widths of the recurrences for *all* trajectories are as-

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FIG. 1. Angular distributions for $\pi^{-}p$ backward elastic scattering. The Brookhaven National Laboratory–Rochester data are from Ref. 2, the Michigan data marked with a square are from Ref. 5, the Michigan data marked with an open triangle are from Ref. 7, the Iowa State–Minnesota data are from Ref. 6, and the CERN–Saclay data are from Ref. 3. The solid curves are from calculations described in the text.

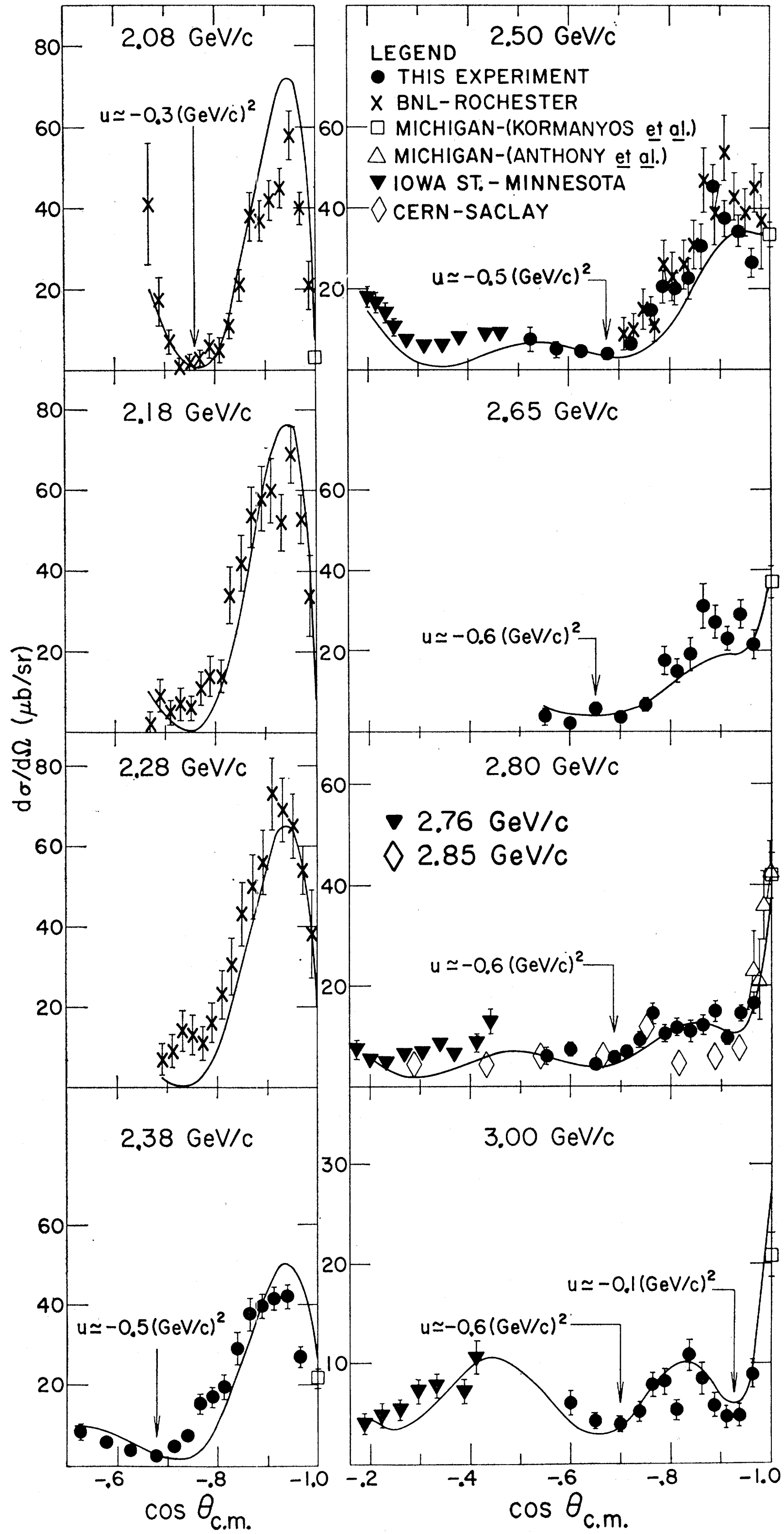

TABLE I. Differential cross sections for $\pi^- p$ backward elastic scattering. Points for which the background subtraction is $\geq 10\%$ are marked with an asterisk (*).

$-\cos\theta_{\text{c.m.}}$	u $[(\text{GeV}/c)^2]$	$d\sigma/d\Omega$ (μb/sr)	$d\sigma/du$ $[\mu\text{b}/(\text{GeV}/c)^2]$
2.38 GeV/c			
0.525	−0.744	8.7±2.0	30±7
0.575	−0.651	5.8±1.3	20±4
0.625	−0.558	4.1±0.9	14±3
0.675	−0.466	2.4±0.7	8±2
0.713	−0.396	5.1±1.4	17±5
0.738	−0.349	7.6±1.7	26±6
0.763	−0.303	15.6±2.4	53±8
0.788	−0.257	17.2±2.4	58±8
0.813	−0.210	19.3±2.8	65±10
0.838	−0.164	29.0±3.8	98±13
0.863	−0.117	37.6±3.8	127±13
0.888	−0.071	39.7±3.1	134±10
0.913	−0.025	41.4±2.9	140±10
0.938	+0.022	42.1±3.0	143±10
0.963	+0.068	27.1±2.4	92±8
2.50 GeV/c			
0.525	−0.801	7.7±3.1	25±10
0.575	−0.703	5.1±1.9	16±6
0.625	−0.604	4.6±1.5	15±5
0.675	−0.506	4.0±1.3	13±4
0.725	−0.408	6.6±1.6	21±5
0.763	−0.335	14.4±3.5	46±11
0.788	−0.285	20.6±4.1	66±13
0.813	−0.236	20.1±4.2	64±13
0.838	−0.187	22.7±5.1	73±16
0.863	−0.138	30.5±5.5	98±18
0.888	−0.089	45.5±4.9	145±16
0.913	−0.040	37.6±4.3	120±14
0.938	+0.010	34.4±4.1	110±13
0.963	+0.059	26.3±3.6	84±12
2.65 GeV/c			
0.550	−0.820	3.6±1.8	11±6
0.600	−0.715	2.2±1.1	7±4
0.650	−0.610	5.5±1.5	16±4
0.700	−0.505	3.5±1.1	10±4
0.750	−0.400	6.5±1.5	19±4
0.788	−0.321	17.3±3.5	52±10
0.813	−0.268	15.2±3.2	45±10
0.838	−0.216	19.2±4.1	57±12
0.863	−0.163	30.8±5.4	92±16
0.888	−0.111	27.0±3.9	81±12
0.913	−0.058	23.2±3.1	69±9
0.938	−0.005	29.1±3.5	87±10
0.963	+0.047	21.5±3.6	64±11
2.80 GeV/c			
0.552	−0.885	5.9±1.6	16±4
0.600	−0.776	7.4±1.4	21±4
0.650	−0.664	4.5±0.9	12±2
0.688	−0.580	5.7±1.2	16±3
0.713	−0.524	7.0±1.4	20±4
0.738	−0.468	9.1±1.6	26±4
0.763	−0.412	14.6±2.0	41±6
0.788	−0.356	10.2±1.7	29±5
0.813	−0.300	11.7±1.7	33±5
0.838	−0.244	10.9±1.9	31±5
0.863	−0.188	11.8±2.1	33±6
0.888	−0.132	14.7±1.9	41±5
0.913*	−0.076	9.6±1.4	27±4
0.938*	−0.020	14.5±1.7	41±5
0.963*	+0.036	16.4±2.0	46±6
3.00 GeV/c			
0.600	−0.857	6.0±1.2	15.6±3.1
0.650	−0.733	4.3±0.8	11.2±2.1
0.700	−0.614	3.9±0.7	10.0±1.7
0.738	−0.523	5.1±1.0	13.2±2.6
0.763	−0.462	7.8±1.3	20.2±3.4
0.788	−0.402	8.1±1.3	21.0±3.4
0.813	−0.341	5.3±1.0	13.7±2.6
0.838	−0.281	10.8±1.5	28.0±3.9
0.863	−0.220	8.4±1.6	21.8±4.1
0.888	−0.159	5.7±1.2	14.8±3.1
0.913*	−0.099	4.6±1.1	11.9±2.9
0.938*	−0.038	4.7±1.1	12.2±2.9
0.963*	+0.023	8.9±1.4	23.1±3.6

TABLE II. Values of the parameters used in fitting backward $\pi^- p$ elastic scattering from 2.1 to 3 GeV/c with direct-channel resonances. The resonances listed here are the lowest-mass states for the trajectories used in the fit. (See text for definition of these parameters.) The 17 quantities marked with an asterisk were adjusted in the fit. The values in parentheses are from the Particle Data Group tables (Ref. 10).

Isospin	Mass (MeV)	J^P	Γ_1 (MeV)	x_1	a (GeV^{-1})	b (GeV^{-2})
$\frac{3}{2}$	1236	$\frac{3}{2}^+$	120 (123)	1.00 (1.00)	0.18	0.50
	1630	$\frac{1}{2}^-$	160 (160)	0.25 (0.27)	0.18	10.*
	1880	$\frac{5}{2}^+$	250 (250)	0* (0.18)	0.18	0.50
	1905	$\frac{1}{2}^+$	300 (300)	0.15*(0.25)	0.18	0.50
$\frac{1}{2}$	1470	$\frac{1}{2}^+$	260 (260)	0.70*(0.57)	0.18	0.75*
	1518	$\frac{3}{2}^-$	115 (115)	0.36*(0.52)	0.18	0.50
	1550	$\frac{1}{2}^-$	100 (80)	0.35 (0.34)	0.18	10.*
	1680	$\frac{5}{2}^-$	145 (145)	0.45 (0.43)	0.18	0.50
	1688	$\frac{5}{2}^+$	130 (125)	0.60 (0.61)	0.18	0.50
	1710	$\frac{1}{2}^-$	400*(280)	0.65 (0.66)	0.18	1.08*
	1755	$\frac{3}{2}^-$	150*(?)	0.35*(?)	0.18	0.36*
	1785	$\frac{1}{2}^+$	300*(405)	0* (0.34)	0.18	0.50
	1860	$\frac{3}{2}^+$	500*(335)	0.16*(0.27)	0.18	0.45*

sumed to be given by

$$\Gamma_i = \Gamma_1 + a(M_i - M_1),$$

where Γ_1 and M_1 are the width and mass of the lowest-lying state on the trajectory, Γ_i and M_i are the width and mass of the recurrence, and a is the same constant for all trajectories. Elasticities for the recurrences within a trajectory are assumed to fall exponentially:

$$x_i = x_1 \exp[-b(s_i - s_1)],$$

where x_1 is the elasticity and s_1 the square of the mass of the lowest energy resonance on the trajectory; b is a constant which characterizes each trajectory (see Table II). Using the above equations one obtains, for example, $\Gamma = 247$ MeV, $x = 0.33$ for the $\Delta(1940)7/2^+$. For the resonance amplitudes we have used a Breit-Wigner amplitude $[(M-E)/(\frac{1}{2}\Gamma) - i]^{-1}$, where $E = \sqrt{s}$

[10] Particle Data Group, Rev. Mod. Phys. **41**, 109 (1969).

and M and Γ are the mass and width of the resonance.[11]

We have used this model to fit the $\pi^- p$ data from this experiment along with 50 data from Ref. 2 at 2.08, 2.18, and 2.28 GeV/c, nine data from Ref. 5 at 180° and nine data from Ref. 7. The χ^2 for the fit to 138 data points is 510. In fitting these data, we have restricted the parametrization originally proposed by Crittenden *et al.*[9] To reduce the number of adjustable parameters we required that a be the same for all trajectories, as mentioned above.[12] We have also found it possible to use $b=0.5$ for seven of the 13 trajectories. (This value of b gives a fairly good fit to the elasticities of the Δ_δ recurrences.) For the other six trajectories, b was varied[13] between the empirically chosen limits $0.2 \leq b \leq 10$. As shown in Table II, Γ_1 and x_1 were adjusted for several of the lowest-lying resonances in order to improve the agreement of the model with the data. We make no claims of uniqueness for the model we have employed or the parameter values we have used. The chief value of this calculation is that we show that it is possible to reproduce the rich structure observed in $\pi^- p$ backward elastic angular distributions using only direct-channel resonances. We are presently applying this model to all existing $\pi^\pm p \to p\pi^\pm$ and $\pi^- p$ charge-exchange data between 2 and 5 GeV/c for $90° \leq \theta_{c.m.} \leq 180°$.[14]

The observed structure in $\pi^- p \to p\pi^-$ angular distributions in Fig. 1 is not obtained by Regge-pole calculations using the exchange of a single (Δ_δ) trajectory.[15]

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[11] Reference 9 uses a truncated resonant amplitude to fit the $\pi^+ p \to p\pi^+$ data from Ref. 1.

[12] For a discussion of the width function $\Gamma(s)$ see A. Degasperis and E. Predazzi, Nuovo Cimento (to be published).

[13] The fitting routine used was STEPIT, a Fortran IV subroutine copyright 1965 by J. P. Chandler, which is available from the Indiana University Research Computing Center.

[14] M. Ciftan and G. Patsakos have recently compared forward pion-nucleon scattering data with results of four interference models which can be constructed from Regge, resonance, and absorptive amplitudes. They find that a Regge-resonance model based, in part, on Ref. 9 gives a good fit to the data up to $s \cong 25$ GeV^2. M. Ciftan and G. Patsakos, Phys. Rev. D 1, 2156 (1970).

[15] E. Paschos, Phys. Rev. Letters 21, 1855 (1968).

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Study of $\pi^+ p$ Four-Prong Interactions from 2.95 to 4.08 GeV/c*

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In a study of the production mechanism of quasi-two-body final states at the five incident π^+ momenta 2.95, 3.2, 3.5, 3.75, and 4.08 GeV/c, approximately 40 000 events with four outgoing charged particles were investigated. The cross sections for the processes $\pi^+ p \to N^{*++}\rho$, $\pi^+ p \to N^{*++}\omega$, $\pi^+ p \to N^{*++}\eta$, and $\pi^+ p \to N^{*++}f$ have been measured as a function of the pion energy. The differential cross sections and the decay density-matrix elements are discussed in terms of one-meson-exchange models [with absorption (OPEA) and with form factor (OPEW)] and Regge models. For the $N^{*++}\rho$ and the $N^{*++}\omega$ reactions, the joint-decay matrix elements are calculated. The formation of $N^*(2850)$ in the direct channel is also investigated.

INTRODUCTION

IN an effort to extend the available data on production mechanisms of multipion final states, we have studied four-prong events of the types

$$\pi^+ p \to \pi^+ p \pi^+ \pi^- \quad (1)$$

$$\to \pi^+ p \pi^+ \pi^- \pi^0 \quad (2)$$

$$\to \pi^+ \pi^+ \pi^+ n \pi^-, \quad (3)$$

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